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Suppose the curve constructed with coördinates equal to x and y of the preceding table, and that a solid of revolution is generated by revolving it around the axis of Y: evidently, the volume of this solid will represent the total amount of light received by the observer from the whole of the sun's disk, and the volume of the circumscribing cylinder will equal that which would be received if the disk throughout had the same brightness as at the centre. The ratio of these two quantities is, however, obtainable by Simpson's formula, and gives the result 82.6, or the light is about five-sixths of what it would be if the disk had the same brightness at the edges as at the centre. Now, as shown above, the light at the centre is reduced by the atmosphere to 26.1 per cent. Hence the total reduction of the whole surface is $.261 \times .826 = .216$. And, since the light is reduced in every direction by the same amount, we may say that the sun would give out 4.64 times as much light if its atmosphere were removed.

The results of this paper may therefore be summed up as follows. The light of the various parts of the sun's disk is measured by the modification of the Bunsen photometer here employed, and given in the accompanying table, with a probable error not exceeding one per cent except close to the edge. The light at the edge is about .4 of that at the centre. The variations in brightness are nearly those which would be produced by a homogeneous atmosphere of height equal to the sun's radius, and opacity such that only 26 per cent of the light is transmitted. There appears to be a slightly different distribution of the light along the polar, from that along the equatorial, diameter. If the atmosphere were removed, the brightness of the sun's disk would be uniform, and 3.83 times that of the centre of the disk at present. Moreover, the total amount of light would be increased 4.64 times.

VI. — TESTS OF A MAGNETO-ELECTRIC MACHINE.

By E. C. Pickering and D. P. Strange.

The rapidly increasing use of magneto-electric machines as a source of electricity renders accurate tests of the comparative advantages of the various forms and exact measurements of the currents generated under varying conditions very desirable. The machine employed in the following experiments was made by Mr. M. G. Farmer, and consists of a large electro-magnet wound with four coils soldered together at the ends, like four battery cells connected for quantity. Between the poles of this magnet a Siemens' armature is revolved, and both magnet and armature are included in the main circuit. The instrument is therefore extremely simple, and, when the circuit is broken, requires no power to run it except to overcome the friction of the bearings. The total weight is about 700 lbs., and the dimensions 33.5 by 21.5 inches (85 × 55 cms.), with a height of 14 inches (37 cms.). To avoid heating, a water space is left close to the armature, but this is required only when the resistance of the circuit is small.

The quantities to be measured were as follows: 1st, velocity of rotation of armature; 2d, power required; 3d, strength of current with various speeds and resistances; 4th, electro-motive force under the same conditions; 5th, when the current is used to produce a light, a measure of the latter is candle-power.

Power. The boilers and engine of the Institute were used as a source of power. The nominal capacity of the boilers was sixty-six, and of the engine fifteen horse-power; but, owing to various difficulties beyond the control of the writers, only a small portion of this was available, and that only for limited periods of time. A belt passed from the fly-wheel of the engine over a countershaft in the Physical Laboratory, giving it a velocity of about 500 turns per minute. A set of five cone pulleys were attached, by which a speed of 333, 410, 500, 610, and 750 turns could, by shifting a belt, be given to a second shaft. The latter carried a wheel 20 inches in diameter, and drove the machine by a belt passing over a pulley 8 inches in diameter attached to the armature. As the speed of the engine varied somewhat, a speed of from 800 to 2100 turns per minute was thus obtained. Various plans were tried to measure the power employed. For the earlier experiments a Batchelder dynamometer was used, in which the motion was transmitted through four bevel-gears, and the moment of tension measured by a spring-balance and weights. The instrument was not however intended to be run at such high speeds, and the gears were very noisy.

Speed. The number of revolutions per minute is so important a factor in these measurements that it must be constantly determined. At first, a common shaft speeder was employed; but, apart from its want of accuracy, its constant use was laborious, and it showed only the total number of turns during a minute, and not the speed at any intermediate instant. A device was accordingly employed, constructed by Mr. J. B. Henck, Jr., by which these difficulties are completely avoided. The plan is not new, having been published in a modified form many years ago in Nicholson's Mechanics and elsewhere. Three vertical gas-pipes are placed side by side, and connected together below; then half filled with mercury, and so mounted that they may revolve around the axis of the central pipe; a glass tube filled with water is attached to the latter, and serves to show the position of the mercury. Motion was transmitted to the whole from the horizontal shaft of the machine by a spiral spring, as in a dental lathe, but afterwards this was replaced by a pair of bevel-gears. If now the machine is set in motion, the mercury is by centrifugal force thrown from the central to the outer tubes, and the water in the glass tube falls. A graduated scale shows the position of the water, which remains very constant as long as the velocity is uniform, and by its motion shows the slightest variation in speed. The reduction is effected by noting the water level with various velocities as measured by a shaft-speeder, and constructing a curve with coördinates equal to these two quantities. If the tubes are exactly parallel and of uniform diameter, this curve will be a parabola, with axis vertical and parameter determined by the equation $y = 473 \times 10^{-8} n^2 d^2$, in which d is the distance of the outer tubes from the centre in inches, and n the number of turns per second. Evidently an inch would correspond to a much greater change in velocity at high than at low speeds, and accordingly the open ends of the outer tubes were bent in towards the centre. This had the additional advantage of preventing the mercury from being thrown out, and of greatly increasing the range of the instrument. As actually constructed, the speed in turns per minute very nearly equalled the square of the depression of the water level in tenths of an inch.

Resistances. A difficulty at once presented itself in varying the resistance of the circuit, since resistance coils of the ordinary form would be at once injured or even melted by the immense quantity of electricity transmitted. Accordingly a set of resistances were prepared by stretching some uncovered German silver wire along the wall of the laboratory, so as to form nine loops, of eighty feet each, of No. 28 wire. As the diameter is .017 inches, the surface exposed to radiation is about 460 square inches; and, as the air circulates freely around them, there is no difficulty from their heating, even when the machine is connected directly with their terminals. Each of these loops has a resistance of 36.9 ohms, and one or more may be thrown into circuit by a switch. For smaller resistances, a similar device was employed. A frame, 3 feet wide and 6 feet high, was covered on both sides with horizontal wires, passing around screws so as to form 30 loops of No. 22 wire (diameter .029″) and 55 loops of No. 16 wire (diameter .065″). The former had a total resistance of 29.68 ohms, the latter of 9.18 ohms, or the single loops .99 and .167 ohms. To allow for accidental variations in the wire or in the connection, each loop was measured separately, and a table of resistances thus formed. To the end of each loop was attached a short piece of stout copper wire, wound in a helix and sunk in a hole, so that any two could be connected by a wire terminating in copper plugs. By this system, any resistance from .17 ohms to 370 ohms was easily thrown into the circuit, and the connections were few in number and of very small resistance. This plan also had the advantage of extreme cheapness. The heating of the wire was independent of its length, except so far as the current altered. Practically, the three sizes of wire employed would convey 1.5, 5, and 10 vebers, without undue heating. A change of temperature of 100° C. increases the resistance of German silver wire about 4 per cent; and, to allow for this, a so-called thermometer-board was employed, on which pieces of the three wires wound in a helix were stretched. To determine the heating of either size of wire, the proper helix was inserted in the circuit, and a thermometer placed in it. On trial, it was found that the readings were much too high, the radiation prevented by the adjacent spires of the helix much more than compensating for the imperfect connection with the thermometer. This difficulty might be avoided by stretching the helix until these two errors should compensate, which might be tested by covering the helix and a straight wire with iodide of mercury and copper, and altering the form until the color of the iodide changed with the same current in both. As, however, the correction is small at ordinary temperatures, it was deemed best to neglect it, taking care to touch them occasionally when very powerful currents were passing, to make sure that the wires did not become very hot.

Current. A special device is also needed for the determination of the current produced in absolute measure. If an ordinary tangent galvanometer with a single coil of thick wire was employed, the stronger currents could be well compared; but it would be difficult to reduce them to vebers, since a feeble current suitable for depositing copper would not appreciably deflect the needle. Accordingly, a cosine galvanometer shunted was employed, or rather, as here used, a tangent galvanometer, since the coils were kept vertical. The coils consisted of about 50 turns of No. 16 copper wire, 6 inches in diameter, and 3 inches apart. The needle had a length of but $\frac{3}{8}$′, and was made of a piece of watch-spring. An index, 3 inches long, was attached; and the magnet, being suspended by a filament of silk, swung over a graduated circle divided into degrees, and the fractions estimated to tenths by the eye. To eliminate parallax, the bottom of the compass-box was formed of looking-glass, and the eye so placed, when the reading was taken, that the index and its reflection coincided. To determine the constant of the galvanometer, a constant current from a thermal battery was passed through it and through a beaker containing sulphate of copper, and the weight of copper deposited measured. Two determinations were made, and gave the result .052. To make sure that the galvanometer followed the law of the tangents, a series of resistances were interposed in the circuit, and the deflection measured. The results showed that the error was extremely small, even for angles as large as 80° to 85°. The resistance of the galvanometer was .22 ohms, and by it, currents from .02 to .3 vebers could be well measured. For stronger currents a set of shunts were prepared. The wires from the galvanometer were carried parallel to each other and near together for some distance to avoid their disturbing action on the needle, and the resistance thus increased to exactly .25 ohms. Three shunts, *A*, *B*, and *C*, were then prepared, which should reduce the current to .2, .04, and .014, consisting of short stout pieces of German silver wire. The first and second of these were easily made by computing their required resistance, and sliding them in or out of the screw cups in which they were held. They were then tested by passing the same current first through the galvanometer with and without the shunt, and comparing the tangents of the deflections in the two cases. To correct for the change in resistance, an additional resistance was inserted when the galvanometer was shunted. The third shunt could not be made directly, as its resistance was only .0034 ohms, and we could measure directly, only to thousandths of an ohm. The method of comparison alone was therefore used, reading the deflection when the whole current of the machine was passing, and again using the $\frac{1}{25}$ shunt. The correct values of the three shunts were thus found to be .1980, .0392, and .0137. The latter consisted of a bar of German silver, .13″ in diameter and 3″ long. To pass from one shunt to another, a simple switch or plug could not be employed, since the resistance of the shunts *B* and *C* was so small that the variable resistance thus introduced would become quite perceptible, being multiplied many times ; and, moreover, with the stronger currents, the points of contact might become heated or burnt. Accordingly, a switch was inserted in the wire connected with one terminal of the galvanometer, by which it could be connected with either of the three shunts, and a second connection made with each, and with the main circuit. The other terminals of the machine and galvanometer were permanently connected with the other ends of the three shunts.

Another and better method, both as requiring no very small resistances and as employing but a single switch connection, is the following. Call G the resistance of the galvanometer, connect a resistance r' to one of its terminals, and shunt by a second resistance s'. Attach to one end of this a coil r'', and shunt again by the coil s''. If necessary, shunt again until a sufficient reduction is attained. Now connect one terminal of the machine with one end of G, s', and s'', and bring the other in contact with the other end of either of them by a simple switch, and we shall have the effect of three shunts of three different sensibilities. The total resistance and the relative constants may be computed in each case, or they may be measured directly. Calling the total resistances R_1, R_2, and R_3, and the shunts to which they are equivalent S_1, S_2, S_3, we may deduce proper values by the usual formulas for divided currents. As, however, the case is a little complex, it is best to reduce it to the following symmetrical form: Let $f(x, y, z) = xy + xz + yz$; then we have: —

$$R_1 = G \frac{f(r', s', s'' + r'')}{f(G + r', s', s'' + r'')} \qquad S_1 = \frac{f(r', s', s'' + r'')}{f(G + r', s', s'' + r'')}$$

$$R_2 = \frac{(G + r') s' (s'' + r'')}{f(G + r', s', s'' + r'')} \qquad S_2 = \frac{s' (s'' + r'')}{f(G + r', s', s'' + r'')}$$

$$R_3 = S \frac{f(G + r', s', r'')}{f(G + r', s', s'' + r'')} \qquad S_3 = \frac{s' s''}{f(G + r', s', s'' + r'')}.$$

In these equations, G would generally be given; and we may, theoretically at least, assume any five other quantities, and then deduce the remainder. As, however, these equations are too complex to be used with any convenience, let us see how they may be simplified. Suppose that $s' = s'' = G$, and that $r' = r'' = nG$, then our six equations become: —

$$R_1 = G \frac{1 + 3n + n^2}{3 + 4n + n^2} \qquad S_1 = \frac{1 + 3n + n^2}{3 + 4n + n^2}$$

$$R_2 = G \frac{1 + 2n + n^2}{3 + 4n + n^2} \qquad S_2 = \frac{1 + n}{3 + 4n + n^2}$$

$$R_3 = G \frac{1 + 3n + n^2}{3 + 4n + n^2} \qquad S_3 = \frac{1}{1 + 3n + n^2}.$$

If now $n = 1$, or all the resistances equal G, the three values of R become .625, .5, and .625; while those of S are .625, .25, and .2. If $n = 2$, R becomes .733 G, .6 G, and, .733 G, S_1 .733, .2, and .091; $n = 5$

gives R_1 .853 G, .75 G, and .853 G, and S .853, .125, and .0244. Finally $n = 10$ gives R_1 .916 G, .846 G, and .916 G; and C_1 .916, .076, .0073. It will be more convenient in general to give r', r'', s', s'', approximately the proper values, and then measure R_1, R_2, and R_3, by the Wheatstone's bridge. Next interpose resistances in the wires attached to the switch, so as to make the total resistance of the galvanometer the same for all positions of the switch. Thus, in the above example, when $n = 10$, if resistances of .084, .154, and .084 ohms are interposed, the galvanometer resistance will be an ohm in each case. The values of S_1, S_2, and S_3 are now found directly by comparing the deflections when the switch is moved. By this device, the range of a tangent galvanometer may be increased indefinitely, and the strongest as well as weak currents measured by it. Moreover, the resistance is not altered, so that readings with different shunts are directly comparable.

The first experiments made with the machine were for the purpose of determining whether the current was constant under the same circumstances or not. It was feared that, as the magnetism was induced by the current itself, variations would appear, dependent on the time during which the circuit had been closed; but, on trial, it was found that the magnet attained its full polarity sooner than the needle of the galvanometer came to rest, and that, on making and breaking the circuit, the successive deflections were almost precisely equal. The next problem was to determine the effect upon the current of changing the position of the commutator. This is so made as to be capable of being revolved round the shaft of the Siemens' armature through an angle of about 45°, thus taking off the current when the coil of the armature is in different positions relatively to the electro-magnet. Observations were taken with the commutator in the following eight different positions: No. 1 is with the commutator turned farthest down, or with its plane as nearly parallel with the plane of the electro-magnets as possible. It is then turned up through an angle of about 6.5° with each succeeding number. In No. 8, it is very nearly perpendicular to the plane of the magnets. The results of several experiments are given in Table I., in the 2d, 3d, 4th, and 5th columns, of which the current obtained in the various positions is given in vebers per second. In the last four columns, the currents are given in percentages of the maximum obtained.

TABLE I.

1.	2.	3.	4.	5.	6.	7.	8.	9.
1	.0620	.0962	.0436	.1066	96.6	93.8	93.2	92.5
2	.0625	.0986			97 3	96.1		
3	.0631	.0999	.0450	.1115	98.3	97.4	96.2	96.8
4	.0638	.1010	.0455	.1115	99.4	98.3	97.2	96.8
5	.0641	.1021	.0467	.1146	99.8	99.7	99.8	99.5
6	.0642		.0468	.1152	100.0		100.0	100.0
7	.0640				99.7			
8	.0635		.0466	.1152	98.9		99.6	100.0

It thus appears that the position of the commutator has but little influence upon the strength of the current; but, as the maximum was obtained in each case from position No. 6, it was kept in that place in all further experiments.

Next, to determine the relation between the four variables, speed of revolution, resistance in circuit, current, and electro-motive force. An attempt was also made to measure the work required to run the machine, and the coefficient of efficiency; but, from lack of proper dynamometric facilities, the attempt was necessarily abandoned after the first series of experiments.

The results of these experiments are given in the following tables, in which R is the resistance of the circuit, expressed in ohms; S is the speed, or number of revolutions of the armature per minute; C is the current in vebers per second; E is the electro-motive force in volts; E_1 is the computed electro-motive force in volts, which would have been obtained with a speed of 1,000 revolutions per minute; W is the work expended, in foot-pounds, including friction. $W.C$ is the work the current is capable of doing, in foot-pounds; and $C.E$ is the coefficient of efficiency of the machine, obtained by subtracting the work required to drive the machine on an open circuit from the actual work W, and dividing the computed work $W.C$ by the remainder.

From an examination of these tables, several important conclusions may be drawn. For large resistances, over 38 ohms for instance, the electro-motive force is nearly proportional to the speed, and is given by the equation $E = .007S$. The advantage of placing the magnet in the main circuit is here in a great measure lost, since the large outside resistance so far reduces the current that its effect on the magnet is slight. The constant .007 affords a good means of comparing various machines of this form, since its magnitude depends directly on the arrangement of the magnet and armature. For resistances less than

TABLE II.

R.	S.	C.	E.	E_1.	W. C.	W.	C. E.
264.6	750	.023	6.10	8.13	.104	306	
227.4		.027	6.09	8.11	.121	306	
190.3		.032	6.08	8.11	.143		
153.2		.040	6.08	8.11	.178		
116.0		.052	6.10	8.13	.238		
78.9		.078	6.16	8.22	.335		
52.6		.131	6.88	9.04	.664		
41.7	760	.159	6.67	8.76	.788		
41.5		.162	6.72	9.02	.816	309	
27.6	745	.336	9.28	12.45	2.34	328	
21.8	745	.587	12.79	16.9	5.64		
15.44	740	1.42	21.14	28.5	22.5	550	.096
11.44	730	2.20	25.16	34.5	41.5	697	.105
7.50	725	4.17	31.29	43.1	97.9	955	.146
5.15	725	5.29	27.24	37.5	108.1		
4.44	720	6.32	27.43	38.1	124.9	1274	.122
4.44	580	6.96	30.91	53.3	161.4	984	.228
2.97	425	11.26	33.39	78.5	282.1	952	.362
2.78	590	8.62	23.96	40.6	154.9	1403	.133
2.30		9.71	22.32	39.8	162.4		
1.956	530	10.05	19.66	37.1	148.2		
1.786	310	11.58	20.68	66.7	179.6	735	.284
1.656	520	11.30	18.68	35.9	158.3		

TABLE III.

R.	S.	C.	E.	E_1.
333.6		.020	6.62	6.96
296.5	950	.022	6.58	6.91
259.3		.026	6.64	7.00
222.5		.030	6.62	7.02
185.7	940	.036	6.67	7.09
148.8		.045	6.73	7.13
111.6	945	.061	6.85	7.25
74.5		.092	6.87	7.29
37.95	940	.206	7.80	8.29
30.48	925	.476	14.51	15.7
26.57	925	.594	15.78	17.0
21.65		.899	19.47	21.1
16.70	920	1.96	32.73	35.6
13.76		2.72	37.42	41.1
11.77	905	3.41	40.11	44.3
9.81	900	4.39	43.07	47.9
8.94	890	5.06	45.25	50.9
7.80	870	5.86	45.70	52.6
6.92	840	4.90	33.9	40.4
5.91	670	6.17	22.3	33.3
3.93	550	6.76	26.6	48.4
2.95	510	9.40	27.7	54.4

TABLE IV.

R.	S.	C.	E.	E$_1$
333.6	1170	.025	8.31	7.11
296.5		.028	8.31	7.11
259.3		.032	8.33	7.14
222.5		.037	8.34	7.19
185.7	1160	.045	8.36	7.21
148.8	1140	.057	8.41	7.38
111.6	1120	.076	8.44	7.54
74.5	1110	.115	8.54	7.70
37.95	1100	.230	8.73	7.98
74.5	1140	.127	9.44	8.29
37.95	1140	.252	9.58	8.61

TABLE V.

R.	S.	C.	E.	E$_1$.
333.6	1330	.030	9.93	7.47
296.5		.033	9.86	7.42
259.3	1320	.038	9.80	7.42
222.5	1320	.044	9.88	7.49
185.7	1325	.053	9.86	7.46
148.8	1325	.066	9.83	7.45
111.6	1320	.090	10.05	7.62
74.5		.137	10.20	7.73
37.95	1325	.293	11.14	8.56
21.2	1380	1.37	29.01	20.86
16.3	1365	1.99	32.26	23.2
12.3	1350	3.15	38.7	28.7
8.6	1300	4.98	42.8	32.9
7.6	1280	5.78	43.9	34.3
6.6	1230	6.96	46.0	37.4
5.6	960	7.17	40.2	41.8
4.8	880	7.75	36.5	41.4
4.1	850	8.11	33.2	39.1

TABLE VI.

R.	S.	C.	E.	E$_1$.
333.6	1620	.036	12.01	7.41
296.5	1615	.040	11.92	7.38
259.3		.047	12.27	7.56
222.5		.054	12.02	7.42
185.7	1630	.065	12.05	7.39
148.8		.082	12.19	7.48
111.6	1625	.109	12.22	7.57
74.5		.165	12.29	7.61
37.95	1625	.332	12.60	7.80
26.2	1675	1.31	34.31	20.5
21.2	1675	1.82	38.59	23.1
16.3	1675	2.45	40.01	24.0
12.3	1635	3.42	47.06	28.8
8.6	1260	4.82	41.47	54.4

TABLE VII.

R.	S.	C.	E.	E_1.
333.6	2010	.041	13.7	6.81
296.5		.046	13.6	6.78
259.3		.053	13.7	6.93
222.5		.063	13.9	6.81
185.7	2010	.074	13.7	6.77
148 8		.092	13.6	6 62
111.6	2015	.120	13.4	6.65
74.5		.174	13.0	6.39
37.9	2015	.317	12.0	5.96

38 ohms, the electro-motive force rapidly increases by an amount which is approximately given by the formula, $E = S\ (.042 - .0009\ R)$, from which we see that the electro-motive force continually increases as we diminish the resistance, and, if the resistance could be reduced to zero, would attain the value $E = .042\ S$.

The column E_1 is computed by assuming the electro-motive force proportional to the velocity. This column can be used more conveniently than that marked E, since with small resistances the power required was so great as to make the belts slip, and greatly diminish the speed.

In Table II. some measurements of the power are given, as also the ratio of the theoretical power to that actually employed. The latter was measured by the dynamometer, the former computed by the very convenient theoretical formula, $W = \frac{3}{4}\ CE$. From the results, it will be seen that, for large resistances, the power employed, beyond that required to drive the machine, is insignificant, but rapidly increases as the resistance diminishes; the efficiency also at the same time increasing and attaining its greatest value with the smallest resistances. Of course, the absolute efficiency, or ratio of electricity generated to power expended, would be still less than this, being very small for large resistances, and attaining a maximum of about 30 per cent. When we consider, however, how large an amount of work is consumed by even a small amount of heat, the coefficient in the above cases must be regarded as large.

A series of experiments was next made to determine the strength of the current generated in different positions of the armature. The apparatus was constructed by Mr. S. J. Mixter, and consisted of a wooden wheel attached to the armature, and revolving with it. On this rested a brass wire; and a strip of copper was inserted in the wheel, so that it established contact between the axle and the wire, through an angle of about 10°. The latter was supported by a second larger wooden wheel, which could be turned and held in any desired position by inserting a pin in one of a series of holes in its circumference, at intervals of 10°. The experiment was performed by connecting the brass wire and axis of the machine with the galvanometer, so that during each revolution of the armature the current would be for an instant diverted through the galvanometer, these currents following each other so rapidly when the machine was running as to produce a sensibly constant deflection. The larger wheel was then turned 10°, and the observation repeated. The 0° and 180° of this wheel correspond to the points where the circuit is reversed by the commutator.

TABLE VIII.

P.	C.	C.
0	.0498	.1015
10	.0503	.0912
20	.0378	.0786
30	.0338	.0693
40	.0284	.0620
50	.0257	.0514
60	.0211	.0399
70	.0159	.0392
80	.0136	.0385
90	.0130	.0392
100	.0141	.0446
110	.0152	.0588
120	.0188	.1000
130	.0343	.1329
140	.0638	.1406
150	.0715	.1367
160	.0678	.1260
170	.0629	.1162
180	.0498	.1015

Table VIII. gives the result of two series of experiments of this kind, the wheel being turned through 360° and the mean of the two readings at intervals of 180° taken. Column 1 gives the angle through which the wheel has been moved, and column 2 the current, the main circuit having a resistance of 16.7 ohms, and the galvanometer circuit a resistance of 1.3 ohms. Column 3 in like manner gives the current when the resistance of the main circuit is reduced to 10 ohms. An examination of this table shows that the current at no point becomes zero, but varies from a maximum at about 145° to a minimum at 90°. If the distance of the poles of the magnet was large compared with the motion of the armature, the current would vary as the sine of the angle, supposing that there was no induction or other disturbing cause. Accordingly, the current would become zero at two points midway between its two maxima, and this would be the point where the commutator should be placed. In that case, no spark would be seen at the commutator, since the circuit would be broken only when the current was zero. In practice, it was found that there was no portion of the commutator where the spark could be entirely avoided when the resistance was small, evidently owing to the fact shown by these observations, that the current at no point is zero. Moreover, on constructing the curves with coördinates equal to the angles and currents, it will be seen that the inclination is much greater before than after the maximum ; so that the latter, as stated above, is distant only about 55° from the minimum, instead of 90°. The cause of the deviation from the curves of sines is probably the current induced by the magnet, which adds or subtracts its effect according as the current is increasing or diminishing.

In trying experiments upon the light produced by the current, several difficulties were encountered. One of the most serious of these was from the slipping of the driving belts, when the machine was running at high rates of speed and the circuit was made through so small a resistance as the regulator and light. From this cause, we were unable to obtain a steady speed of more than, 1,300 revolutions per minute, which was not sufficient to give the best results. A further difficulty was experienced from the great difference in power required to run the machine when the current was passing, and when the carbons became so far separated that the current was unable to pass. A change of probably 4 or 5 horse-power was thus almost instantly made, whenever the current was made or broken, and the consequent shock upon the machinery was very great. It also appeared that the form of regulator used (Duboscq's) was not capable of controlling the current so that the light should be steady. When the carbons were brought in contact, the current was so great that the magnet acted strongly, starting the reversing clock-work and separating them half an inch or more. This broke the circuit, and the machine began to revolve very rapidly ; soon the carbons were brought together, throwing a great strain on the engine, and thus they oscillated, producing a very bright light for an instant and then extinguishing it. Better results would probably be attained without the reversing arrangement, by a change in the magnet of the regulator, or by increasing the electromotive force of the current. Some results were however obtained by a very careful adjustment of the spring holding the armature. With a velocity of 1,130 revolutions, a tolerably constant light was obtained.

Current, 3.65 vebers. Resistance in circuit, about 10 ohms. Resistance of light, 3.3 ohms. With a speed of 1,325, total resistance 9 ohms, and current 5.71 vebers, a light varying from 600 to 900 candle-powers was obtained. With a speed of 1,280, resistance 7 ohms, and current 5.20 vebers, the light varied from 650 to 900 candle-powers. Doubtless a much greater light could be obtained with a different regulator and means of obtaining a high speed.

The effects of the current were very fine, and have been frequently described in connection with the Wilde, Gramme, and other machines. Thick wires were melted, heavy weights sustained in the air in the interior of large coils, and excellent diamagnetic effects shown. The induced current on breaking the circuit was very severe when taken through the body, and the spark very long and bright.

The advantages of this machine are its simplicity, compactness, and small weight, compared with other machines of equal power; and little or no trouble was experienced from heating with the currents here employed. In conclusion, we wish to express our hearty thanks to Mr. Farmer for lending us the machine, and hope that we may be enabled to continue these experiments with this and other machines next year, if we can secure an adequate motor and proper means of measuring power.

VII. — ANSWER TO M. JAMIN'S OBJECTIONS TO AMPÈRE'S THEORY.

By William W. Jacques.

It is the purpose of this paper to answer some objections which M. Jamin has made to Ampère's theory of magnetism.

In the Comptes Rendus for Jan. 12, 1874, M. Jamin published the results of some experiments, in which he obtained the laws of the distribution of magnetism in a soft iron bar which formed the core of two coils by measuring the force necessary to detach an armature when placed at different points along the bar. He gives the equations to the curves obtained by sending an electric current through one of the coils, through both coils in the same direction, and through both coils in opposite directions; and finds that the force necessary to detach the armature at any given point is less when the currents are parallel than when opposed; from which he draws essentially the following conclusions: —